Nonlinear and Independent Control of Active and Reactive Powers and a Double Fed Induction Generator

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Abstract

This article about decentralized control wiring rotor induction machine with two pieces of three-phase bridge converter with DC link connected between the rotor and network will discuss and independent control of active and reactive power of induction generator with double feed "DFIG" which is used for electricity generation in variable speed wind power plants, is considered. In this article with use of feedback linearization method "the controller is designed with the goal of independent control over the stator active and reactive power". That works in the high and low speed synchronous. As regards stator voltage measured by the sensor, however, the stator flux should be estimated by means of tracking stator voltage (instead of tracking flux). After the proof of the relations and equations required in centralized control, a model representing separate active power and reactive power control, in the induction generator DFIG is simulated in Matlab-Simulink environment and the results have been reviewed.

Keywords

Nonlinear Control; Active and Reactive Power; Induction Generate; Independent Control

Introduction

According to the data recorded during the last 30 years increased require to energy for generate electricity significantly. wind power is one of the most affordable types of renewable energy. Double feed induction generator most common type of generator for wind turbine.

One of the most important and widely used systems is double fed induction generators (DFIG). This type of machine is wiring rotor. This machine are connected to the network so that its stator directly and rotor through two sided converters. The perspective control induction machine control is a complex issue, and these systems are multi-input and multi-output, nonlinear and parameter uncertainties.

Double fed induction generator control is used of method vector control tracking of the stator flux. and PI controllers are used. Simulation results in [1, 4, 7] related to the vector control Problems such as: Lack of coupling in the transient mode and creating lasting error. This problem creates duse to ignore the stator resistance. In this paper nonlinear control method are solved mentioned problems, in this method used of tracing stator voltage (instead of tracking the flux) [3, 10, 11]. Also noteworthy is a general weakness in the vector control methods that act only in the steady state tracking is achieved. To solve this problem in a synchronous reference coordinate system where d-axis is along the grid voltage vector, a robust nonlinear controller based on linear methods of input – output will be design and implementation. Purpose of controller design is calculated and applied voltages of the two axial rotor. This paper is organized as follow. Section 2 deals with double fed induction machine model with state feedback controller design and main result of the paper is presented. In Section 3, simulation results are executed to verify the validity of the proposed approach.

Double Fed Induction Machine Model with Controller Design

In this part of the Dq reference frame d-axis is aligned with the grid voltage space vector is used. In this case the flux in a three-phase stator and at all times regardless of the dynamic system will sync directly with the stator voltage. Space air gap flux vector (λgap) in the major machine almost 90 degrees is lag than stator voltage, and ratio this position will not change in a wide range the result network flux tracing is similar to machine flux tracing with a relocation 90 degrees.

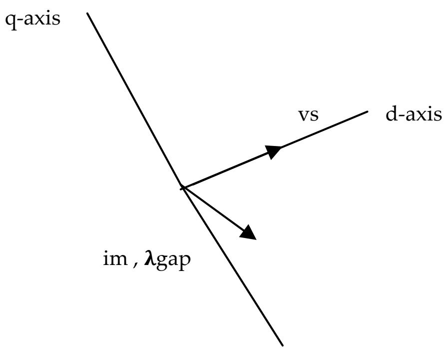


FIG. 1 AIR GAP FLUX VECTORS AND STATOR VOLTAGE

For power control of method state feedback input-output used to trace the network flux. Tracking stator voltage is not effective in the induction machine control. Although little difference in the stator flux tracking and network tracking, but have practical importance. The importances of tracking stator voltage (flux network) instead of the stator flux tracking controller design are as follow:

- Being much more accurate and easier to tracking stator voltage.
- There are errors in the estimation of parameters and because of the lack of direct measurements of flux in the stator flux tracking.
- Tracking the stator voltage by the voltage sensor can be done faster.
- Increase system stability.
- Smooth connected and without transient state windings stator to the network during setup.

However, assuming a linear magnetic model, two central equations of induction machine rotor winding, with the selection current and the stator flux as state variables are expressed as follows:

$$\frac{d\omega}{dt}=\frac{1}{j}.[\mu.(\psi_d i_q-\psi_q i_d)-T_l]$$
$$\frac{di_d}{dt}=-\gamma.i_d+\omega_2.i_q+\frac{\alpha}{\sigma}.\psi_d+\frac{\omega}{\sigma}.\psi_q+\frac{u_{sd}}{\sigma}-\beta.u_{rd}$$
$$\frac{di_q}{dt}=-\gamma.i_q-\omega_2.i_d+\frac{\alpha}{\sigma}.\psi_q-\frac{\omega}{\sigma}.\psi_d-\beta.u_{rq} \tag{1}$$
$$\frac{d\psi_d}{dt}=-R_S.i_d+\omega_o.\psi_q+u_{sd}$$
$$\frac{d\psi_d}{dt}=-R_S.i_q-\omega_o.\psi_d$$

where i_d ، i_q ، ψ_d ، ψ_q stator currents and two central flux. And u_{rd} and u_{rq} are rotor two central voltage, u_{sd} is stator d-axis voltage, ω_o and U angular velocity and amplitude of stator voltage respectively. ω is rotor velocity Electrical radians per second, $\omega_2=\omega_o-\omega$ is Rotor frequency (slip frequency), J is Machine inertial and T_L is Load torque. Parameters μ , γ ، σ ، α Are defined as follows:

$$\mu=\frac{3P}{2},\gamma\left(\frac{\alpha}{\sigma}L_S+\frac{R_S}{\sigma}\right),\sigma=L_S(1-\frac{L_m^2}{L_rL_s}),\beta=\frac{L_m}{L_r}$$
$$\alpha=\frac{R_r}{L_r} \tag{2}$$

In addition, active and reactive power components injected into the stator circuit are:

$$P_S=1.5u_{sd}i_d$$
$$Q_s=-1.5u_{sd}i_q \tag{3}$$

from the before equation with selection elements i_d ، i_q where corresponding to the stator active and reactive reference currents, The purpose of the nonlinear controller design calculated and applied voltages of the two central u_{rd} and u_{rq} is such that:

$$\lim_{t\to\infty}\left(i_d-i_d^*\right)=o \qquad \lim_{t\to\infty}\left(i_q-i_q^*\right)=o \tag{4}$$

Input-output Feedback control design for the winding rotor induction machine with current and stator flux errors are defined as follows:

$$\tilde{i}_d=i_d-i_d^* \quad , \quad \tilde{i}_q=i_q-i_q^*$$
$$\tilde{\psi}_d=\psi_d-\psi_d^* \quad , \quad \tilde{\psi}_q=\psi_q-\psi_q^* \tag{5}$$

Using the equations of two central the induction machine rotor winding for the stator flux error dynamics are:

$$\frac{d\tilde{\psi}_d}{dt}=-R_s\cdot\left(\tilde{i}_d+i_d^*\right)+\omega_o\cdot\left(\tilde{\psi}_q+\psi_q^*\right)+u_{sd}-\psi_d^*$$
$$\frac{d\tilde{\psi}_q}{dt}=-R_s\cdot\left(\tilde{i}_q+i_q^*\right)+\omega_o\cdot\left(\tilde{\psi}_d+\psi_d^*\right)-\psi_q^* \tag{6}$$

with selection:

$$\psi_d^*=\frac{(-R_s.i_q^*-\psi_q^*)}{\omega_o}$$
$$\psi_q^*=\frac{(-R_s.i_d^*-u_{sd}+\psi_d^*)}{\omega_o} \tag{7}$$

Equations are converted to linear form (ψ_d and ψ_q There are two central stator flux reference), Also, using the two central equations of induction machine rotor winding, dynamic error of the stator currents is:

$$\frac{d\tilde{i}_d}{dt} = -\gamma.\left(\tilde{i}_d + i_d^*\right) + \omega_2.\left(\tilde{i}_q + i_q^*\right) + \frac{\alpha}{\sigma}.(\tilde{\psi}_d + \psi_d^*)$$
$$+\frac{\omega}{\sigma}.\left(\tilde{\psi}_q + \psi_q^*\right) + \frac{u_{sd}}{\sigma} - \beta.u_{rd} - i_d^*$$
$$\frac{d\tilde{i}_q}{dt} = -\gamma.\left(\tilde{i}_q + i_q^*\right) - \omega_2.\left(\tilde{i}_d + i_d^*\right) + \frac{\alpha}{\sigma}.(\tilde{\psi}_q + \psi_q^*)$$
$$-\frac{\omega}{\sigma}.\left(\tilde{\psi}_d + \psi_d^*\right) - \beta.u_{rq} - i_q^* \tag{8}$$

Using method exact linearization feedback reference voltage vector components of the axial rotor for command to the inverter side of the rotor:

$$u_{rd} = \frac{1}{\beta}.(-\gamma.i_d^* + \omega_2.i_q^* + \frac{\alpha}{\sigma}.\psi_d^* + \frac{\omega}{\sigma}.\psi_q^* + \frac{u_{sd}}{\sigma} + v_{rd} - \frac{di_d}{dt}$$
$$u_{rq} = \frac{1}{\beta}.(-\gamma.i_q^* - \omega_2.i_d^* + \frac{\alpha}{\sigma}.\psi_q^* - \frac{\omega}{\sigma}.\psi_d^*$$
$$+v_{rq} - \frac{di_q}{dt} \tag{9}$$

By letting the last two equations, equation error dynamical system is obtained as follows:

$$\frac{d\tilde{i}_d}{dt} = -\gamma.\tilde{i}_d + \omega_2.\tilde{i}_q + \frac{\omega}{\sigma}.\tilde{\psi}_d + \frac{\omega}{\sigma}.\tilde{\psi}_q - u_{rd}$$
$$\frac{d\tilde{i}_q}{dt} = -\gamma.\tilde{i}_q - \omega_2.\tilde{i}_d + \frac{\omega}{\sigma}.\tilde{\psi}_q - \frac{\omega}{\sigma}.\tilde{\psi}_d - u_{rq}$$
$$\frac{d\tilde{\psi}_d}{dt} = -R.\tilde{i}_d + \omega_o.\tilde{\psi}_q \tag{10}$$
$$\frac{d\tilde{\psi}_q}{dt} = -R.\tilde{i}_q - \omega_o.\tilde{\psi}_d$$

The new variables are defined as:

$$v_{rd} = k_i\,\tilde{i}_d \tag{11}$$
$$v_{rq} = k_i\,\tilde{i}_q$$

where in that k_i is controller coefficients. By using Lyapunov stability criterion can be indicate that the system is stable:

$$x = [\tilde{i}_d, \tilde{i}_q, \tilde{\psi}_d, \tilde{\psi}_q] \tag{12}$$

Adding an integral sentence to v_{rd} and v_{rq} for improved stability and robust controller is Effective.

Simulation Results

Active and reactive power control Block diagram is shown in figure 2. According to figure 2, in motorized modes instead active power control, machine speed is controlled. In this mode is used PI-controller.

The purpose of the simulation DFIG model and its controller is making zero steady state error. After model generator using the above relations and controller Making model using existing relationships intended targets will be reviewed.

Simulation this machine is possible in mode below synchronous and top synchronous generator. In this paper we investigate the below synchronous generator mode, In this simulation, the network frequency is 50 HZ and line to line voltage is 380V and controller coefficients are calculated using the method try and error so that reduced steady state error and ripple and be zero. Stator active power reference until two seconds in the -550W, from two to four seconds 500W, from four to six seconds -200W, after the sixth second has been placed in the value of -400W. Stator reactive power reference until sec second 330 var. from two to four seconds 250 var. then is placed the amount 350 var.

It has been shown active and reactive power changes with the reference values in the figure 3. In the figure 3 section (a) is shown reference values active power in the time and section (b) from this figure express changes active power this section say exact tracing active power by system. In the figure 3 section (c) is view stator value reference of reactive power in the time that section (d) also present exact tracing reactive power by system. In total will see the actual values of the active and reactive power is close to the reference values where can be expressed tracking the reference values. Also to express power independence and fit decoupling active and reactive power, Figure 4 shows the active power and reactive rotor, we expect according to relationship: Pr= -SPs the rotor power is smaller than the stator power, and also in area below the synchronous generator rotor active power is positive, these two verified with carefully to figure 4. In Figure 5 is shown the two central values of stator currents in the synchronous reference frame. According to relationship between stator active and reactive power, Stator current d-component changes similar the active power and stator current q-component changes is similar to the reactive power but with negative sign.

for examine the performance of nonlinear controller is different method but in this paper by changing the 15 percent resistance in the stator we review stator active and reactive power control, such a way that in simulates all the resistance values of the stator and rotor (not controller) will increase by 15 percent and again we see the desired output, is noticeable, although there was a little ripple in the stator and rotor but stator active and reactive power control was well.

Figure 6 is shown reference values and actual stator active power and reactive. Figure 7 is shown the indicate values of two-axis stator current in synchronous reference frame. In mode top synchrouns generator although reference values active and reactive power is as well as below synchrouns.

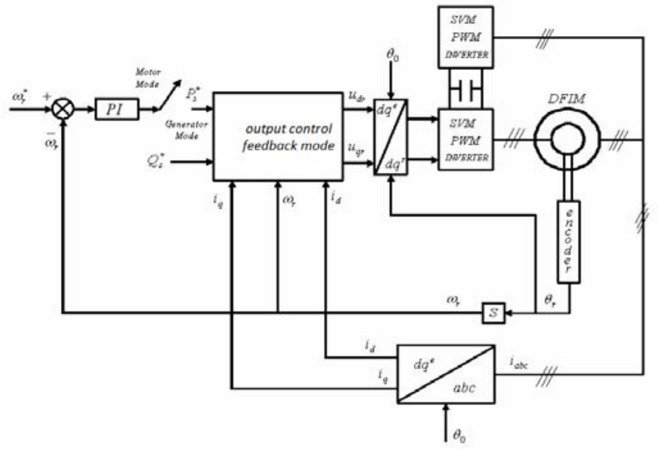
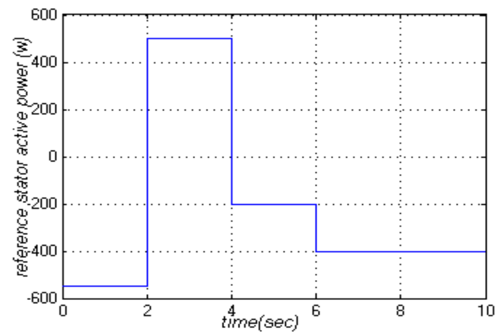
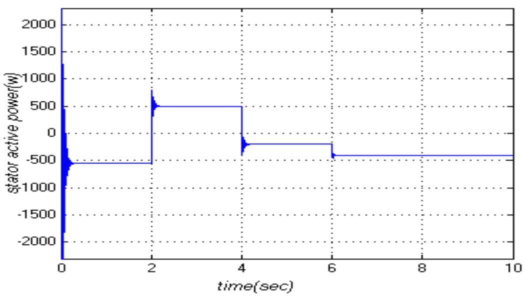


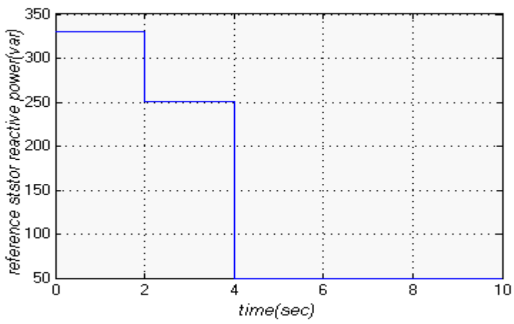
FIG. 2 NONLINEAR CONTROL DRIVE –BLOCK DIAGRAM [9]



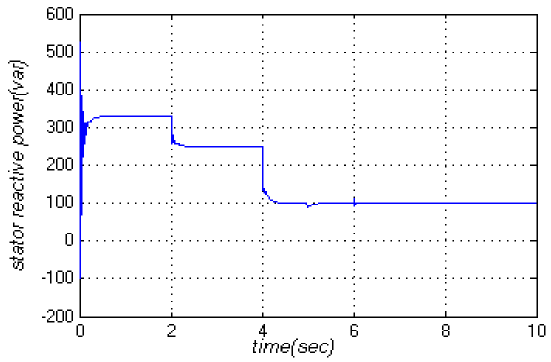
(a)



(b)



(c)



(d)

FIG.3 REFERENCE VALUES AND ACTUAL STATOR ACTIVE POWER

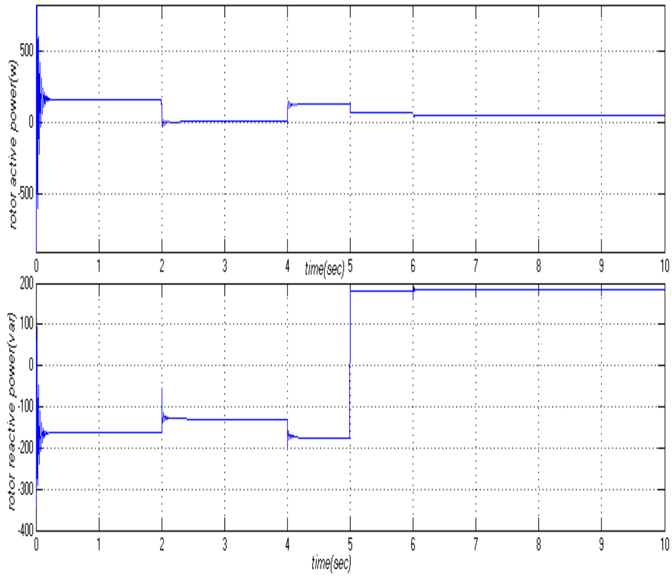


FIG. 4 THE VALUES OF ACTIVE AND REACTIVE POWER ROTOR

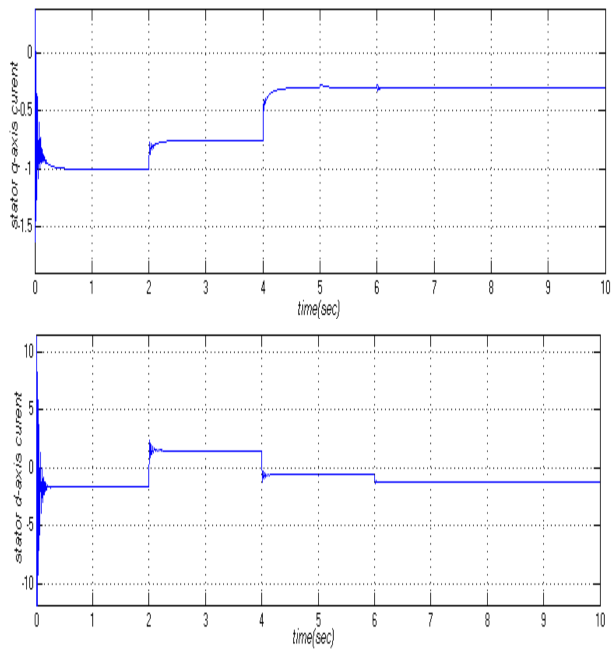


FIG. 5 THE VALUES OF TWO AXIAL CURRENTS STATOR IN THE REFERENCE FRAME SYNC

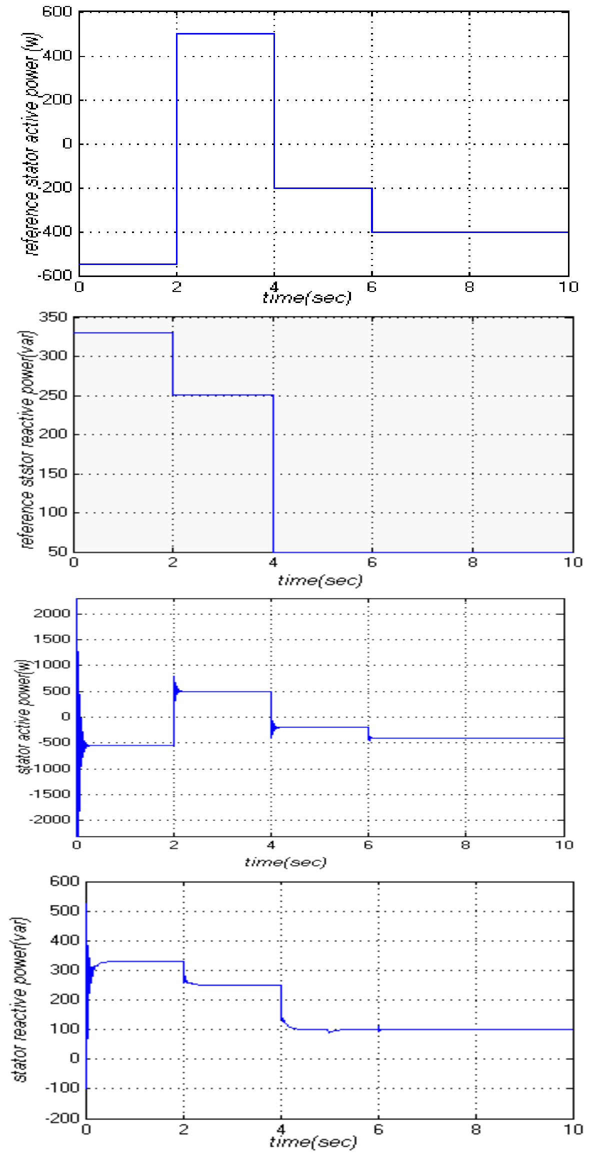


FIG. 6 REFERENCE VALUES AND ACTUAL STATOR ACTIVE POWER INCREASE OF 15 PERCENT IN THE STATOR AND ROTOR RESISTANCES

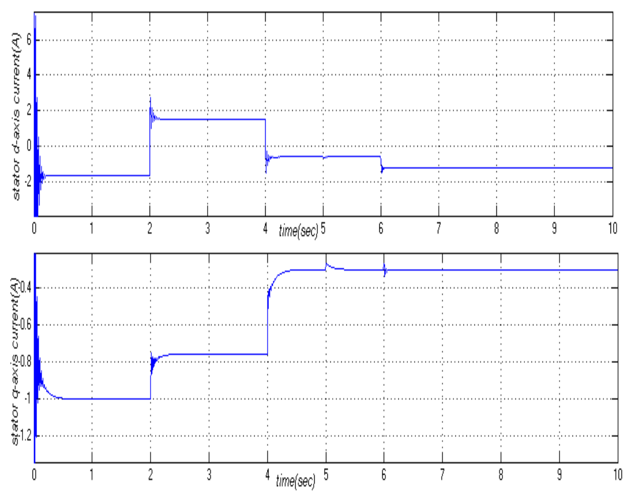


FIG. 7 THE TWO CENTRAL VALUES OF STATOR CURRENTS IN INCREASED 15 PERCENT RESISTANCES STATOR AND ROTOR

Conclusions

The Use of linear and nonlinear methods for the control of active power and reactive in double fed induction generator was presented in this paper. After reviewing other control of active and reactive methods in the induction generator including traditional method vector control and other existing methods in several papers, we understand by using input-output nonlinear feedback control method has the advantages.

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